A comparison of load-velocity and load-power relationships between well-trained young and middle-aged males during three popular resistance exercises

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ABSTRACT

This study examined the load-velocity and load-power relationships among 20 young (age 21.0 ± 1.6 y) and 20 middle-aged (age 42.6 ± 6.7 y) resistance trained males. Participants performed three repetitions of bench press, squat and bent-over-row across a range of loads corresponding to 20 to 80% of one repetition maximum (1RM). Analysis revealed effects ($P < 0.05$) of group and load x group on bar velocity for all three exercises, and interaction effects on power for squat and bent-over-row ($P < 0.05$). For bench press and bent-over-row, the young group produced higher barbell velocities, with the magnitude of the differences decreasing as load increased (ES; effect size 0.0 to 1.7 and 1.0 to 2.0, respectively). Squat velocity was higher in the young group than the middle-aged group (ES 1.0 to 1.7) across all loads, as was power for each exercise (ES 1.0 to 2.3). For all three exercises, both velocity and 1RM were correlated with optimal power in the middle-aged group (r = .613 to .825, $P < 0.05$), but only 1RM was correlated with optimal power (r = .708 to .867, $P < 0.05$) in the young group. These findings indicate that despite their resistance training, middle-aged males were unable to achieve velocities at low external loads and power outputs as high as the young males across a range of external resistances. Moreover, the strong correlations between 1RM and velocity with optimal power suggest that middle-aged males would benefit from training methods which maximise these adaptations.

KEY WORDS

Bench press, squat, bent-over-row, sarcopenia, dynapenia, ageing

INTRODUCTION

Current demographic trends indicate that the number of middle-aged people (30 to 59-year-olds) in the U.K. is increasing (33), with the expectation that the number will rise from 25.7 million in 2014 to 26.3 million in 2020. Improvements in medical care and a greater appreciation for factors that enhance longevity are said to contribute to these demographic changes (5). Alongside this transformation is the growing number of middle-aged athletes (42), who, despite the inevitable declines in athletic ability owing to the ageing process (5, 42), strive to maintain or improve their athletic performance. Examples of such age-related declines have been documented by Pantoja, Villarreal, Brisswalter, Peyre-Tartaruga and Morin (34) who reported an ~ 1% decline per year between the ages of 25 and 96 years in maximal velocity and power outputs during a 30 m sprint, and by Baker and Tang (5) who noted a 25% difference in weightlifting performances (World Records) of those in 30- and 60-year-old age categories.

Impairment in athletic performance as an athlete ages is largely due to the age-associated changes in muscle quality illustrated in muscle atrophy (i.e. sarcopenia; 30) and a loss of muscle strength and power (i.e. dynapenia; 11, 21). Early work by Frontera and colleagues (17) suggested that sarcopenia was a major factor when explaining dynapenia. However, more recent longitudinal and cross-sectional research has indicated that sarcopenia cannot fully account for the loss of strength and power with ageing (18, 36), which instead is thought to be related to an impaired contractile velocity (36), an increase in non-contractile tissue (i.e. infiltration of fat into the muscle; 18) and fascicle length (29), impaired ATPase activity in a given fibre (25), excitation-contraction ‘uncoupling’ (35), a decrease in the number of motor units (10) and an impaired ability to activate the surviving motor units (24).

Losses in power with ageing are well established (11, 21, 36). For example, during elbow and knee flexion and extensions, older males (56 to 79 years) produced lower power than their younger (18 to 31 years) counterparts at both slow (1.05 rad·s) and fast (3.14 rad·s) movement velocities (11). Though, because Candow and Chilibeck’s (11) group was healthy, but not physically active, the older group might have been more susceptible to these age-associated decrements. When activity levels, but not resistance training, were matched between young (23.1 ± 1.2 years) and old (61.8 ± 2.6 years) males, these age-associated differences were found to remain (31). During more complex multi-jointed tasks (i.e. bench throws and countermovement jumps) performed by habitually active males, Izquierdo et al. (21) also observed an impaired upper- and lower-body power production in older (65.0 ± 4.1 years) compared to middle-aged (42.0 ± 2.9 years).

Regarding the factors which might contribute to power, studies by Bean and colleagues (7, 8) determined that leg strength was highly correlated (r = 0.89 and 0.76, respectively) with lower-body power in 72.7 (± 4.6) and 74.1 (± 6.6) year olds, respectively. That similarly high correlations have also been documented in young populations (4), highlights the importance of strength to power production regardless of age (3). However, despite power being a product of force and velocity, and Petrella and colleagues (36) suggesting that age-related decreases in power are caused by impaired contractile velocity, no study has established the nature of the relationship between power and velocity specifically in middle-aged males. Such information would elucidate some of the variables (i.e. strength and velocity) that contribute to power in middle-aged males and thus have practical implications for future training models.

The literature on ageing and power is typically health-related and incorporates cohorts of people aged 60 years and above, many of whom neither play sport nor resistance train. As such, the differences in power between the young and old populations are unsurprising. From the perspective of strength and conditioning practitioners who coach athletes of all ages, it would be helpful to know if these findings extend to middle-aged males who habitually resistance train and play sport. If these age-associated reductions are still present in such people, it could be problematic for those who want to be competitive, given the importance of power for many sporting tasks in general, and playing standard in particular (3, 39). However, as no study has investigated this, the purpose of this study is to provide a detailed analysis of the load-velocity and load–power relationships during multi-jointed exercise in young (18 to 25 years) and middle-aged (35 to 55 years) males who regularly resistance-train (for a minimum of two years). A further aim is to determine the relationship of strength and velocity to power output in these age groups to elucidate the factors which contribute to power in resistance trained middle-aged males.

METHODS

Subjects

Twenty young (21.0 ± 1.6 years) and 20 middle-aged (42.6 ± 6.7) males, with a minimum of two years of resistance training (4.5 ± 1.1 and 16.9 ± 11.4 years for young and middle-aged groups, respectively), were recruited via convenience sampling from the University population and local gymnasia for this study. Thirty-five years was selected as the lower boundary for the middle-aged group because it is the entry age for ‘Masters’ athletes (see British Masters Athletic Federation and World Masters Athletics). As age-related studies typically use older groups (60 years and over), 55 was selected as the upper-limit for the middle-aged group. A sample size of 38 (19 per group) was estimated using G*power 3.1 (14) based upon an effect size, alpha error probability and power of 1.1 (as observed between groups by Aoki and Demura (2) for handgrip power at 50% maximal voluntary contraction), 0.05 and 0.95, respectively. All participants used the bench press (BP), squat (SQT) and bent-over-row (BOR) as part of their training programmes. Participants completed a pre-test health questionnaire and provided written consent for the study, which was approved by the Ethics Committee of the Faculty of Life Sciences at the University of Chester. Participants were instructed not to consume any ergogenic supplements (for example, caffeine) on the day of testing and to refrain from strenuous exercise in the three hours before testing. If it did not conflict with the current study, participants continued their normal training programmes. Moreover, discussions with participants before testing revealed no symptoms of perceived muscle soreness or weakness.

Study Design

This study comprised a mixed factorial design in which two groups of participants attended the laboratory on two occasions and provided repeated measures during three resistance exercises. On the first visit, anthropometric measurements of stature, body mass and body composition were recorded, followed by assessments of maximal strength on BP, SQT and BOR, and familiarisations to the measures of barbell velocity and power. Participants were considered 'familiarised' when they could complete three consecutive repetitions that produced power within ±10% of each other (6). Participants returned to the laboratory 48 hours later to complete three repetitions of BP, SQT and BOR at loads corresponding to 20 to 80% one repetition maximum (1RM; at 10% 1RM increments) in a randomised order for both exercise and load.

Procedures

Biometric measurements

Body mass and stature were determined using digital scales (Seca 813, Hamburg, Germany) and a wall-mounted stadiometer (Harpenden, Holtain, Crymych, Dyfed, UK), respectively. Body density (Db) was estimated via skinfold measurements (Harpenden, British Indicators, Burgess Hill, UK) taken at the tricep, abdominal, suprailliac and mid-thigh sites and incorporated into the Jackson and Pollock (22) equation:

$$\text{Db} = (0.29288 \times \sum \text{skinfolds}) - (0.0005 \times \sum \text{skinfold}^2) + (0.15845 \times \text{age}) - 5.76377$$

Body fat percentage (%BF) was derived from Db using the Siri (40) equation:

$$\%\text{BF} = [(4.95/\ \text{Db}) - 4.5] \times 100$$

From this quantities (kg) of fat-mass (FM) and fat-free mass (FFM) were derived to determine any age-associated differences in body composition between the groups.

Training history

Participants completed a questionnaire that required them to detail how many years they had participated in regular resistance training, their weekly training frequency and session duration, and the main reason for their training. This information was collected to help elucidate any age-related differences that might be observed.

Strength testing

Participants' maximum strengths on the BP and BOR exercises were assessed directly using a standardised 1RM protocol (41). For safety reasons, 1RM for SQT exercise was predicted via a five-repetition maximum (5RM) protocol as outlined by Reynolds, Gordon and Robergs (37) using the equation:

1RM (kg) = 1.0970 x (5RM weight [kg]) + 14.2546

The above equation was reported to yield accurate 1RM predictions (R^2 = 0.988, standard error of estimate = 13.51 kg).

Assessment of peak power and velocity

Peak power and velocity were assessed during the three exercises at loads corresponding to 20, 30, 40, 50, 60, 70 and 80% 1RM. Loads were applied in a randomised order with measurements of peak velocity and power recorded using a FitroDyne rotary encoder (Fitronic, Bratislava, Slovakia) attached directly under a Smith machine bar (Smith Machine standard, Perform Better, Leicester, UK) by its nylon cable. The FitroDyne measures rate of displacement and thus assumes that the nylon cord is moving in a vertical plane. Any deviation from this plane could increase measurement error. As such the Smith machine was employed as it restricts the movement of the nylon cord to the vertical plane only. The FitroDyne is deemed to provide a reliable marker of moderate changes in peak power and velocity during the selected exercises (15).

For the BP exercise, the participant held the bar with a prone grip and lowered it to his chest, before maximally pushing it until full elbow extension. For the SQT exercise, with the bar positioned across their shoulders participants descended until their hips were below the knee joint and then ascended as rapidly as possible until their knees were at full extension. A bench was employed to ensure that each participant attained the same depth and range of motion on each repetition. During BOR exercise the participant commenced in a bent-over position (i.e. back angle of approximately 45º), before pulling the bar maximally until the elbows reached full flexion. For all exercises participants were instructed to perform the eccentric phase in a controlled manner and the concentric phase as rapidly as possible. Three repetitions of each exercise were performed at each load with self-selected rest intervals that were capped at 90 s, but ranged from 30 to 90 s. Rest times were self-selected as lighter loads did not require the same recovery time. Peak velocity values were recorded from which peak power (W) was calculated (load x 980 $cm \cdot s^{-1}$ x velocity). For each exercise the load that represented maximal power was deemed the optimal load. Total peak power was calculated as the sum of peak power values of all seven loads.

Statistical Analyses

Comparisons of categorical training history variables (i.e. weekly training frequency, session duration and reason for training) by group were made using a Chi-squared (χ^2) test of association. Categorical data was deemed to show significant trends if $P < 0.05$. Biometric variables and training years were analysed via an independent *t* test. Peak values of velocity and power were averaged for the three repetitions at each load and their distributions checked for normality and homogeneity of variance using the Shapiro-Wilk and Levene statistics, respectively. Both assumptions were found to be satisfied ($P > 0.05$). Accordingly, a two-way (load x group) analysis of variance (ANOVA) was used to assess the variation of scores. If the assumption of sphericity was not met the Greenhouse-Geisser correction was used. Partial correlation coefficients were calculated to provide an estimation of the contribution of maximal velocity (at 20% 1RM) and 1RM to power at the load that optimised power (50, 80 and 80% 1RM for BP, SQT and BOR, respectively). For all partial correlations, the variables not being analysed were controlled for (e.g. the relationship between maximal velocity and power, controlling for 1RM. Effects sizes (ES) for velocity and power output were determined using Cohen's *d,* calculated as the difference between the means divided by the pooled standard deviation of the two groups (20). The practical significance of the findings was quantified as: trivial <0.2, small 0.2-0.59, moderate 0.6-1.19, large 1.2-1.9, and very large >2.0 (20). All data analyses were performed in SPSS (Version 21, IBM SPSS Inc, Chicago, Il.)

RESULTS

Biometric measures and training history

Mean body mass was not different between groups ($P > 0.05$, ES = 0.31), though the young group had a higher fat-free mass ($t_{(38)} = 2.6$, ES = 0.85) and lower fat mass ($t_{(37.9)} = 3.0$, ES = 0.96) compared to the middle-aged group ($P < 0.05$). A group x exercise type interaction was noted for 1RM ($F_{(1.4,\ 50.8)} = 6.4$, $P < 0.05$), with the middle-aged group being weaker ($P < 0.05$) in each exercise, particularly the SQT (-27.7%), than the young group (Table 1).

[Table 1 about here]

The middle-aged group had regularly resistance-trained longer than the young group ($t_{(19.4)} = 4.8$, $P < 0.05$, Table 2), but there was a trend for the middle-aged group to conduct their training with a lower weekly frequency ($\chi^2 = 8.1$, $P < 0.05$) and shorter session duration ($\chi^2 = 18.9$, $P < 0.05$). Additionally, the middle-aged group typically resistance-trained to improve strength and health, whilst the young group trained solely for hypertrophy and strength gains ($\chi^2 = 13.9$, $P < 0.05$).

[Table 2 about here]

Peak velocity

For BP, the group ($F_{(1,\ 38)} = 10.5$, $P < 0.05$, ES = 1.7 to 0.0) and load ($F_{(2.1,\ 79.4)} = 943.4$ $P < 0.05$) effects reflected mean values that were greater for the young group, and decreasing as load increased; Figure 1A. The load x group interaction ($F_{(2.1,\ 79.4)} = 14.1$, $P < 0.05$) revealed narrowing group differences as intensity increased, whereby effects were small and trivial from 60% 1RM onwards. Similar patterns of variability to BP were observed for both the SQT and BOR exercises, albeit the group differences were consistently greater across all loads, and remained moderate and large even at the higher intensities (Figures 1B & 1C)

[Figure 1 about here]

Peak power

As expected from the velocity data, the group effect on BP peak power ($F_{(1,\ 38)}$ = 31.4, P < 0.05; Figure 2A) was significant, with the young group producing higher values than the middle-aged group at all loads (ES = 1.1 to 2.0). Likewise, the effect of load was significant ($F_{(1.8,\ 65.6)}$ = 943.5, P < 0.05), with peak power being highest (optimised) at 50% 1RM in each group, though the interaction effect was not (P > 0.05). The patterns of peak power values for the SQT and BOR exercises were similar to each other, reinforcing the aforementioned group and load effects seen for bench press. However, distinctive for these two exercises was the optimised values occurring at the highest loads (80% 1RM), and significant (P < 0.05) load x group interactions reflecting (generally) group differences widening with increasing intensities (Figures 2B & 2C).

[Figure 2 about here]

Total peak power was significantly higher in the young group compared to the middle-aged group during BP (3996.7 ± 707.3 and 2969.3 ± 623.6 W, respectively, $t_{(38)}$ = 3.4, P < 0.05), SQT (6597.8 ± 1452.5 and 4197.5 ± 1090.4 W, respectively, $t_{(36)}$ = 5.9, P < 0.05) and BOR (4798.3 ± 1031.4 and 3493.6 ± 745.3 W, respectively, $t_{(38)}$ = 4.9, P < 0.05). Moreover, an interaction effect (group x exercise) was observed for total power with the magnitude of the differences being greater between the groups for SQT and BOR (ES = 2.0 and 1.6, respectively) compared to BP (ES = 1.1; Figure 3).

[Figure 3 about here]

Partial correlations

For BP exercise in the young group only, 1RM was significantly correlated (Table 3) with optimal power output (r = .863, $P < 0.05$) when controlling for velocity, whereas correlations for both velocity and 1RM were strong and significant in the middle-aged group (r = .846 and .782, respectively, $P < 0.05$). Both velocity (r = .591) and 1RM (r = .614) were moderately correlated with optimal power output during SQT exercise in the middle-aged group ($P < 0.05$), while in the young group these correlations were moderate (r = .653) and strong (r = .877), respectively, during SQT exercise ($P < 0.05$). During BOR, optimal power output in the young group was only related to 1RM (r = .725, $P < 0.05$) whilst both velocity and 1RM was strongly correlated to power output in the group ($P < 0.05$).

[Table 3 about here]

DISCUSSION

This is the first study to provide a comprehensive cross-sectional analysis of the load-velocity and load–power relationships in young and middle-aged athletes who regularly resistance-train. Importantly, these findings indicate that middle-aged, resistance trained males are unable to achieve the high velocities and power outputs during multi-jointed resistance exercises produced by younger counterparts.

Despite between-group similarities in body mass, the middle-aged athletes had a lower fat-free mass and a higher fat-mass than the younger athletes. These age-associated differences in body composition are expected and well documented (11, 36). As skinfold assessment reflects subcutaneous fat, differences between age groups are probably explained by more intra-muscular adipose tissue (18) present in the middle-aged group, and their training history, typically incorporating shorter and less frequent resistance training sessions. This idea of a lower training volume would reflect the documented age-associated increases in time spent involved in other activities, such as working (45) and family-related responsibilities (42). Moreover, the middle-aged males chose resistance training to maintain health and strength, whereas the younger males tended to train this way to increase strength and hypertrophy. Such differences in training goal orientation between groups have also been noted among Masters athletes who reported training for ‘general health’ and ‘weight concern’ (32).

As expected, the middle-aged group was weaker than the young group for all three exercises. These differences in muscle strength are similar to those noted previously for both the upper (11, 17, 21) and lower body (11, 17, 21), and likely explained by age-associated differences in muscle quality (16) and motor unit number (10) and activation (24). The aforementioned training focus of the two groups is again pertinent, with the younger group’s specific concern being that of improving strength (and hypertrophy) and, unlike the middle-aged group, not health. As adaptations to resistance training appear to be specific to the type of training regularly performed (9), it is unlikely that the middle-aged group optimised strength gains from their health-related training. This difference in training approach in the middle-aged group might explain the lower velocities and power outputs achieved in this group, that is, they do not train specifically to increases these components.

For all exercises and loads except 60 to 80% 1RM BP, the young group produced higher barbell velocities than the middle-aged group. Although only Valour et al. (44) generated statistics in the same manner as the current study (ES = 0.98 for maximal velocity elbow flexion), statistical differences between age groups have been documented in upper-body pushing (21), lower-body (1, 25, 36) and upper-body pulling exercises (43). Although not measured in this study, it is plausible that the age-associated differences in fascicle length (28, 29), reduced ATPase activity (25) and changes in contractile properties (i.e. increased slow myosin heavy chain content; 44) which contribute to maximal velocity contractions, contributed to the poorer performance of the middle-age group. Indeed, the small to non-effects at 60 to 80% 1RM BP might be explained by the low movements velocities exhibited by both groups. That is, the mechanisms noted above might not be sufficient to induce these age-associated differences when movement velocities are very low. That there were differences in barbell velocities between the groups during SQT and BOR at 60 to 80% 1RM, when the average barbell velocities were higher (111.9 ± 16.0 to 132.6 ± 18.0 and 110.9 ± 23.6 and 137.4 ± 21.8 $cm \cdot s^{-1}$ for SQT and BOR, respectively) than BP (66.6 ± 16.1 to 103.6 ± 16.3 $cm \cdot s^{-1}$), would support this notion.

Power output during BP, SQT and BOR was superior in the young athletes, with moderate to very large differences between groups. Whilst Allison et al. (1) and Jozsi et al. (23) have noted very large (ES = 1.86) for leg press, and small to moderate effects (0.23 to 0.95) for seated arm pull between young and old groups, many more studies have observed statistical differences between young and older groups during upper-body pushing (11, 21) lower body (11, 21, 36) and upper-body pulling exercises (2, 11, 43). As for velocity (above) such discrepancies in power can be explained in terms of reduced calcium release (35), fascicle length, and subsequent force production (28, 29), and an impaired motor unit activation and number (10, 24). That the effects between age groups in the current study were greater for power than velocity (for all exercises) suggests that the lower strength of the middle-age athletes more likely accounted for their lower power outputs than barbell velocity.

The greater between-group differences observed in lower-body total power and strength than upper-body sits well with prior literature reporting site-specific strength and power disparities (11, 26, 31). Though the phenomenon is not particularly well understood, it has been suggested that during daily living lower-body movements are supplemented by upper-body contributions (e.g. using the upper-body to rise from a chair; 27) and the lower-body undergoing more severe changes in muscle contractile units (e.g. decreases in the specific tension of type 1 and 2 fibres; 25) and connective tissues (e.g. increases in fat and connective tissue; 26). Practically, these site-specific differences in strength and power suggest that middle-aged athletes may need to undertake methods to offset such differences.

For BP, strength was strongly correlated (*r* > 0.84) with power output in both young and middle-aged groups, reaffirming the work of others (3, 4). However, unlike previous research, velocity was strongly correlated with power output only in the middle-aged group. This suggests that higher power production in upper-body pushing exercise in middle-aged males is achieved from greater strength and higher barbell velocity, whereas in the young group higher power is achieved via greater strength only. For SQT exercise, strength was highly (*r* = 0.877) and moderately (*r* = 0.614) correlated with power output in the young and middle-aged athletes, respectively, and reaffirms previous findings among young (4) and older populations (7, 8). Power output illustrated a moderate relationship with velocity in both groups during SQT exercise. It appears that the middle-aged group is equally reliant on strength and velocity when producing power during SQT exercise. Thus, it would be appropriate for both young and middle-aged males to focus increasing on both strength and barbell velocity to increase their power. For BOR, strength formed a strong relationship with power in both the young and middle-aged groups (*r* = 0.725 and 0.711, respectively). The reason for the non-significant correlations between velocity and power in the young group, but strong correlations in the middle-aged group, is unclear but does indicate that to increase power middle-aged athletes require improvements in both strength and velocity. Collectively, this correlation data supports the notion that to produce high power, individuals must first be relatively strong (3). It has been noted that in older populations (~71 year olds) that high-velocity power training to be more effective than low-velocity/high-strength training (38). Thus, middle-aged athletes would benefit from adopting a training approach which maximises both strength and velocity adaptations.

PRACTICAL APPLICATIONS

Though a cross-sectional design, this study provides a comprehensive analysis of the load-velocity and load–power relationships exhibited during three popular exercises among resistance-trained young and middle-aged males. These data indicate that in comparison to younger athletes, middle-aged athletes were unable to achieve high barbell velocities at low external resistances. Moreover, power during BP, SQT and BOR was particularly diminished in the middle-aged group. These impairments in velocity and power might explain some of the age-associated decreases in sporting performance previously reported in middle-aged athletes. Given the strong relationships between strength and velocity with power in the middle-aged group, such athletes should undertake specific training methods to improve both components.

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Figure 1. Load-peak velocity relationships in young and middle-aged males during bench press (A), squat (B) and bent-over-row (C) exercises. (Values in *italics* indicate effect sizes; ES).

Figure 2. Load-peak power relationship in young and middle-aged males during bench press (A), squat (B) and bent-over-row (C). (Values in *italics* indicate effect sizes; ES)

Figure 3. Total peak power in young and middle-aged males during bench press, squat and bent-over-row exercises. (Values in i*talics* indicate effect sizes; ES).

Table 1. Biometric characteristics of the young and middle-aged groups

Table 2. Training characteristics of the young and middle-aged groups

Table 3. Partial correlations for velocity (controlling for 1RM) and 1RM (controlling for velocity) with optimal power.